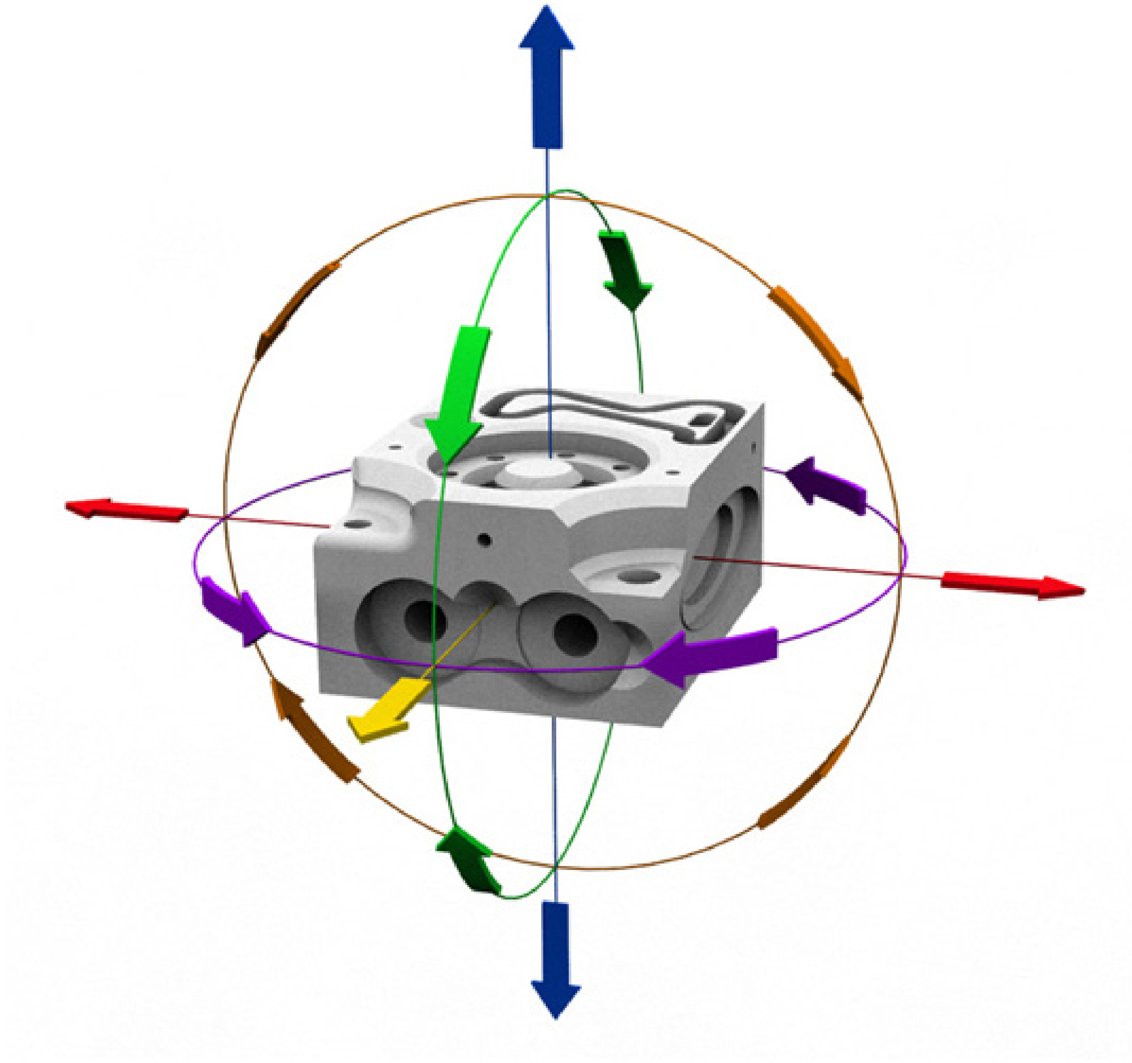
Tutorial
H-1000-5322-01-A

Principles of part alignment



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Principles of part alignment

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Contents

1 Principles of part alignment

1.1 Tutorial pre-requisites

- None

1.2 Tutorial objectives

- Learn concept of degrees of freedom
- Gain an understanding of how a rigid body moves spatially in the measuring volume
- Familiarisation with basic alignment concepts (non-MODUS specific)
- How to determine correct surface selection to align a part
- Examples of various alignment schemes
- Selecting an alignment strategy for a simple rectangular part
- Selecting an alignment strategy for a cylindrical part
- Selecting an alignment strategy for a free form part

2 Introduction

When measuring a part, it is necessary to give the measuring system a set of information that indicates the location and orientation of the piece that is going to be measured. This requires a series of initial measurements and alignment commands. Studying this appendix will help the student gain a better understanding of alignment concepts so they are better prepared to understand the basis of the alignment tutorials. Firstly, common terms used during the part alignment process will be explained.

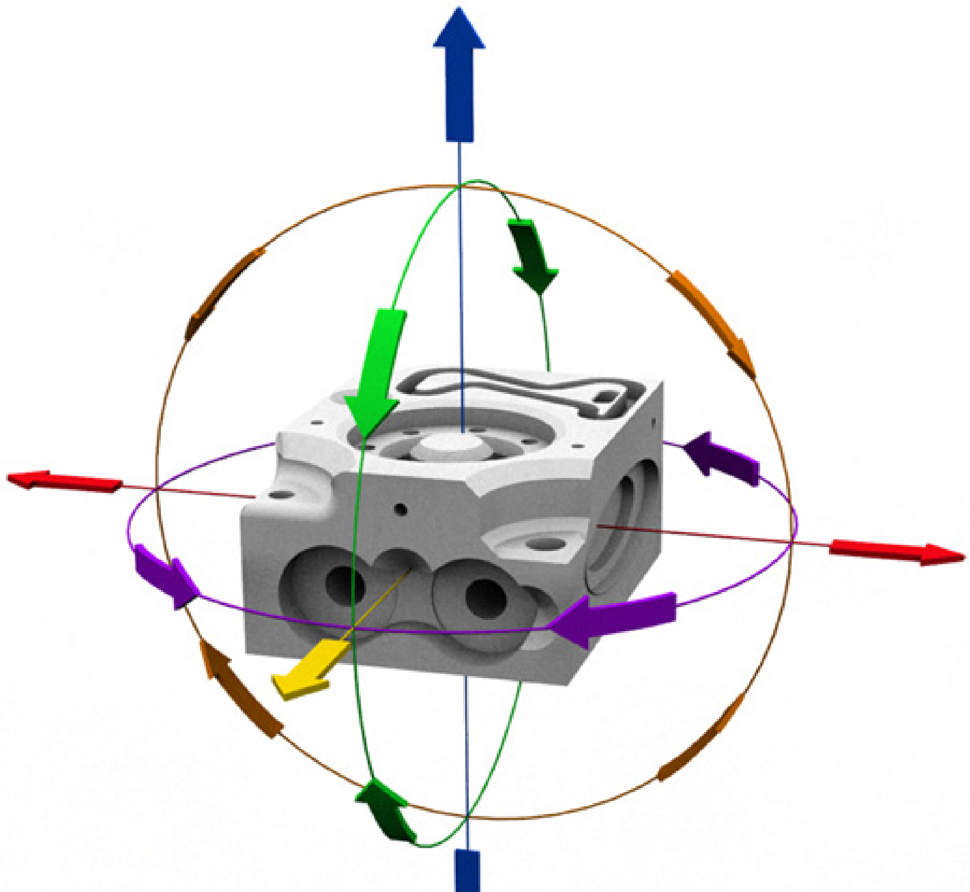
3 What is a degree of freedom (DOF)?

A degree of freedom is a parameter that defines the configuration of a system. The system can be anything. For example, the mechanical error of a coordinate measuring machine has 21 degrees of freedom. Because of the natural error associated with a mechanical system, which can bend and twist, a compensation factor can be applied to account for straightness, roll and pitch of each axis as well as the perpendicularity between each of the CMM axis.

The term degrees of freedom (DOF) is used to analyse the way that a part is sitting in the volume of a CMM. A DOF is a parameter that describes one way that the part can move or rotate in 3-dimensional space. Gaining an understanding of this develops a better understanding of how to create robust alignments in MODUS.

4 Six degrees of freedom of a rigid body

In the case of a part alignment on a co-ordinate measuring machine, there are six degrees of freedom that completely define the exact position and rotational alignment of the measurement artefact. Since the part is a rigid body, it can be assumed that it does not bend or twist. If it did bend and twist, those motions would need to be included in the full definition and there would be more than six DOF. In reality, the part might be subject to some microscopic bending or twisting, but they will be assumed to be negligible. If there is a significant problem with part deformation by clamping or probing forces, an analysis of the holding fixture may be required. By assuming no significant deformation, it can be assumed that the part itself is a rigid system, which simplifies the analysis to six degrees of freedom.



The six degrees of freedom are as follows:

1. Pitch - Rotation around the X axis
2. Roll - Rotation around the Y axis
3. Yaw - Rotation around the Z axis
4. Left / right - Translation or movement in the X direction
5. Front / back - Translation or movement in the Y direction
6. Up / down - Translation or movement in the Z direction

In order to create a robust alignment, each degree of freedom must be considered independently so that MODUS can calculate a set of rotations and translations. These values are saved as named coordinate systems.

5 Why align the work piece?

When beginning a CMM program, the system has no information as to where the part is located in the machine volume. As far as the measurement system is concerned, without defining a part coordinate system, the position of the work piece is at the zero corner of the machine volume where the scale's zero position is defined. In addition, the CMM starting coordinate system assumes that the work piece is perfectly aligned with the three axes of the measuring machine. Therefore, each degree of freedom is assumed to have zero offset and zero rotation from the initial machine zero and axis system.

Since it is impossible and impractical to place the work piece in an exact location and aligned perfectly with the CMM axes, the work piece position and orientation must be determined by measuring features on the part and setting a datum to these measured features. Once a datum is set, measuring of points, planes, circles and other features can be completed. When a datum is created, MODUS keeps a list of six values that define each of the six DOF.

For example, if this line is run in MODUS, there will be one degree of freedom that is set to this value, given no other translations.

D(1)=TRANS/XORIG,54.236

As the datum system gets increasingly complicated, the six transformations will be effected accordingly. With a transformation of -50 in X.

D(1)=TRANS/XORIG,-50.000

There is now a DOF in the X direction of:

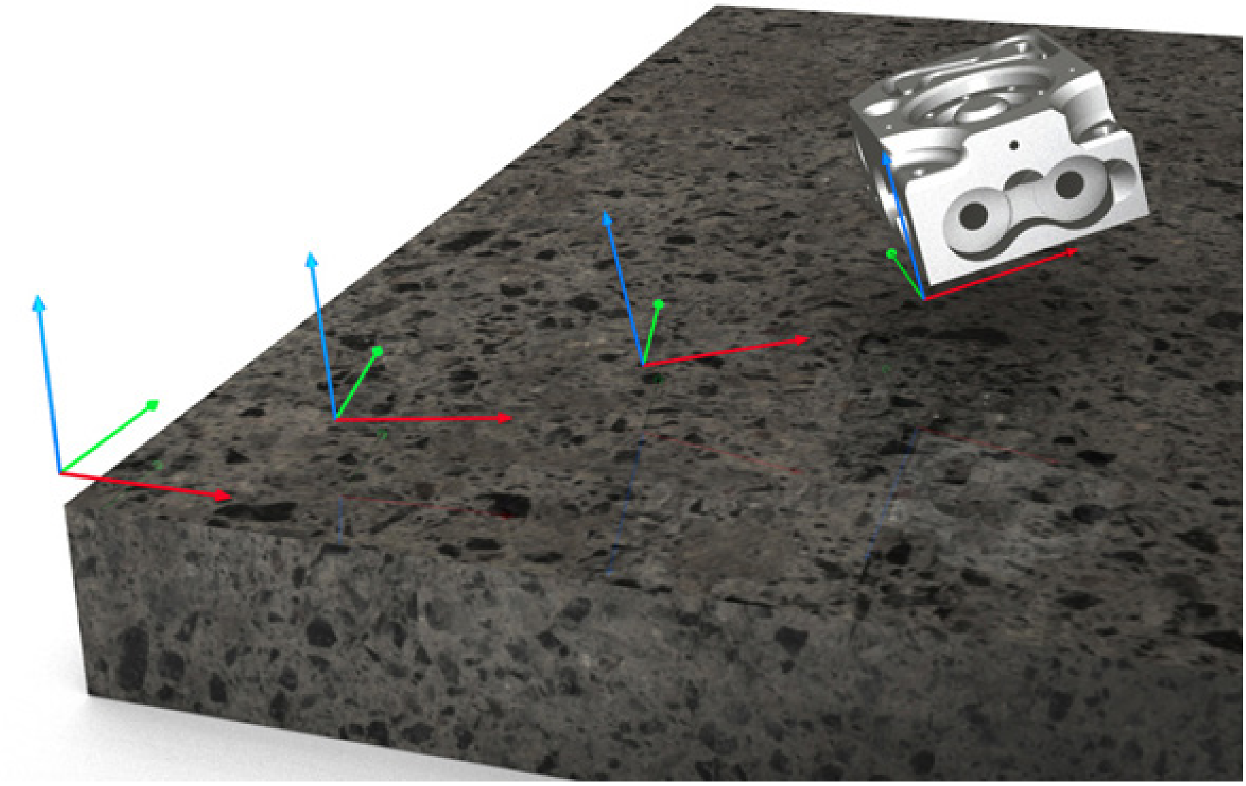
+4.236

This is because of the cumulative effect of both transformations.

6 Moving the datum to the part location

When a datum is set to a part on the CMM, the datum is mathematically transformed to the location of the actual part. This happens when features are measured on the part and datum commands are executed in MODUS. Most datums are more complicated than the previous example, but the same principles apply. When these datum transformation values are determined by feature measurements such as planes, circles and points for example; a named datum is saved to computer memory and a fully defined part datum is set. If needed later, the datums can be saved to the MODUS database, or a separate user defined file (device).

The initial machine coordinate system aligns to the actual part position on CMM:



7 Simple measurement example (non-CMM)

Below is a very simple measurement example that illustrate that the concept of degrees of freedom is not limited only to CMM measurements. Strict control of all degrees of freedom is not always necessary. This simple example of a non-CMM measurement is used to illustrate that even this requires control of at least one of the relevant degrees of freedom.

7.1 Ex 1: Micrometer

When measuring a part with any type of measuring device such as a height gauge, micrometer or calliper; all relevant degrees of freedom must be set first. Often this is done without thinking if using a hand held device.

For example, when measuring an object using a standard micrometer, it must be aligned properly with the object being checked. Otherwise, the reading will be too large. A degree of freedom is being set when aligning the pin so it is perpendicular to the micrometer anvils. The same problem can occur when setting up a part for measurement on a CMM. If the alignment is not correct, the distances and positions of features may be incorrect.

Micrometer is misaligned:

Micrometer is aligned (correct reading):

8 CMM measurement examples

Below are some example scenarios of possible alignments for a work piece on a coordinate measuring machine. It is not an all inclusive list, but is a small sample of some examples to provoke further thought and study.

While it is mathematically more complicated on a CMM, the principle is the same as the previous example: features of the part are measured and datum commands are used to control all the degrees of freedom that are relevant to the measured part. Different types of parts require the use of a variety of feature types to set those degrees of freedom. Usually on a CMM all six degrees of freedom are set. However, like the micrometer example, it is not always necessary to define all six degrees of freedom.

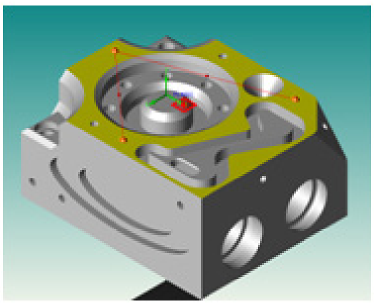
For example, if a height measurement is needed between the surface plate and the top of the part and it does not need to be measured automatically, it may be possible to use the surface plate as a primary axis (two DOF) and set the Z origin to the surface plate as well (one DOF). Then, measure one or more points on top of the work piece to get the height.

To summarise, when writing a program to run automatically or when an entire part needs to be measured, it is likely that all six degrees of freedom need to be constrained. If not, it may be possible to eliminate some degrees of freedom. A better understanding of when a datum setup can be simplified comes with experience. Nevertheless, in any situation the datum setup is one of the most important aspects of a CMM part inspection.

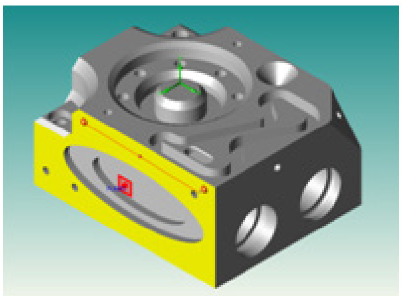
8.1 Ex 3: Rectangular part

There are many possibilities for an alignment of a rectangular shaped work piece. The top plane could be used as the primary alignment, which will remove two rotational (rotation about X and Y) and one translational (Z) degrees of freedom. This takes care of three of the six DOF.

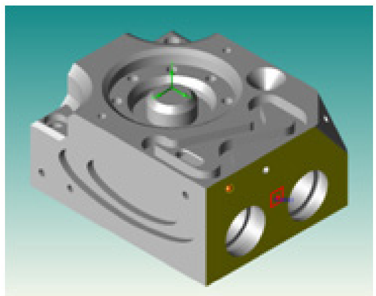
Primary:



Secondary:



Tertiary:



Two DOF can be set by measuring a line on the left edge of the part. Any other edge will work also, as long as the surfaces used are perpendicular with the top surface. In other words, the front, left, rear or right surface would be used to measure the line if using it to set the Z rotation DOF. This takes care of one translation DOF as well leaving only one DOF left to do, in order to have a complete alignment.

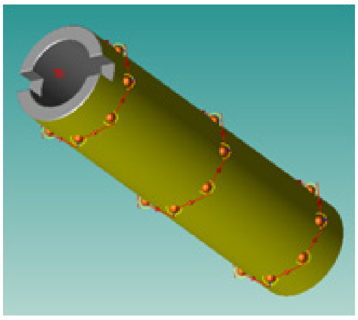
Finally, choose a surface that is simultaneously perpendicular to the other two surfaces used in the datum alignment. A point, line or plane can be used on that surface to zero the final DOF.

8.2 Ex 4: Cylindrical part

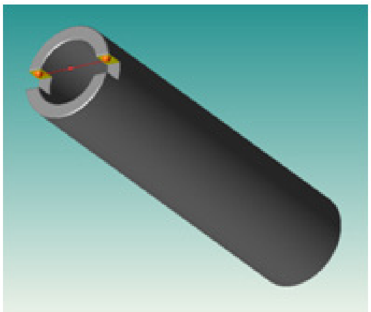
When measuring a cylindrical part, one option would be to set 5 DOF using the top end plane as a primary datum and a circle as the zero point. While this will work, in the example pictured, it would be better to align the primary datum with a cylinder. It is not always obvious which one is best for a primary alignment. The way that the part functions may dictate which is best. For example, if the surface on the end of the part mates with another part, it may be better to use the smaller end surface as the primary datum.

At times, the choice will already be made by the designer if they have assigned a specific feature as the primary datum (refer to ASME Y14.5M-1999 specification for additional information regarding interpretation of Geometric Dimensioning and Tolerancing).

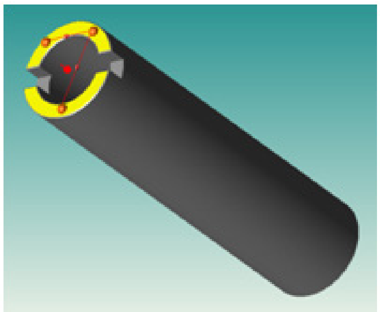
Primary:



Secondary:



Tertiary:



In this example, since the cylinder is longer than the diameter, it is more reliable to use the cylinder. The slot at the top end allows a line measurement to constrain the rotational DOF while the plane at the top can be used to create an origin for the final DOF. The top plane could also be intersected with the cylinder to create a point, which works just as well as the plane for a zero in one direction.

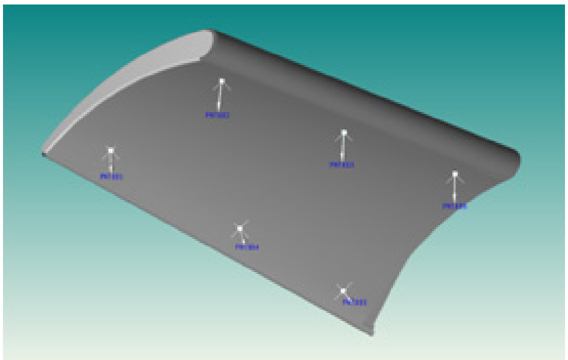
8.3 Ex 5: Free form part

The first examples were of prismatic parts. A prismatic part is one that is made of standard shapes like planes, lines, circles, cylinders and other shapes that are defined easily. A free form part is one that has surfaces that can only be defined mathematically using higher level mathematics such as a NURBS representation for example (Non-Uniform Rational B-Spline). In order to control the position and orientation of a free form surface, it requires a minimum of one point per degree of freedom.

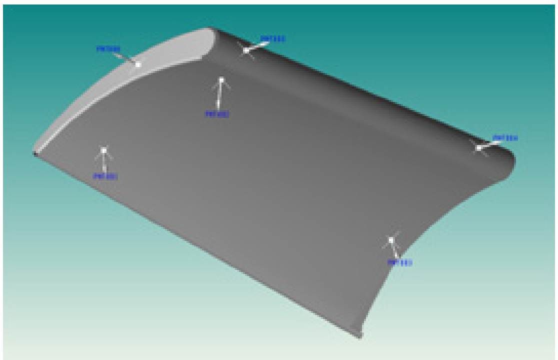
If all six degrees of freedom are to be set, a minimum of six points is needed. It is important to note that the points must be strategically placed in a logical position on the part. It helps to imagine placing the part in a holding fixture or jig. If the points chosen would not accurately constrain the work piece in a fixture, they will not work in a CMM program to control all six DOF.

For example, the six points on the free form surface shown below will not work well, since most of the points have vector directions that point in a similar direction, with only minor differences. If the points were on nest points in a fixture, the part would be able to slide in two directions easily.

Micrometer is misaligned:



Micrometer is aligned (correct reading):



A better choice is to move the points with the following configuration. Here there are three points on the largest surface (controls two rotations and a translation), two points at nearly 90 degrees from the first three points (third rotation and one translation), and one point at about 90 degrees from all the other points (final translation).

NOTE: This set of points must be iterated, or measured several times; each time giving a more accurate representation of the correct position of the point until an acceptable error exists using a 6-point alignment in MODUS (see ‘Advanced alignments’ tutorial for more information).

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